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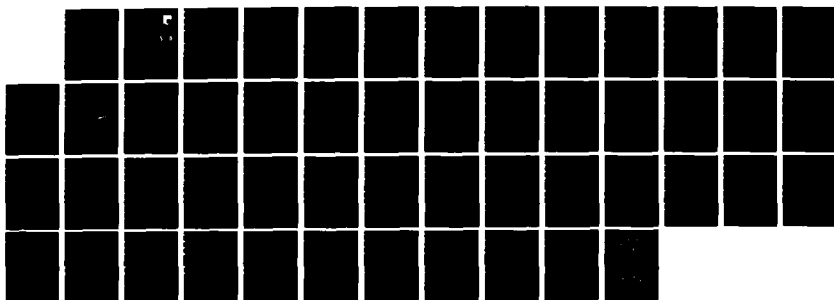
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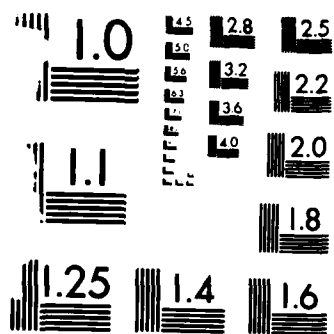
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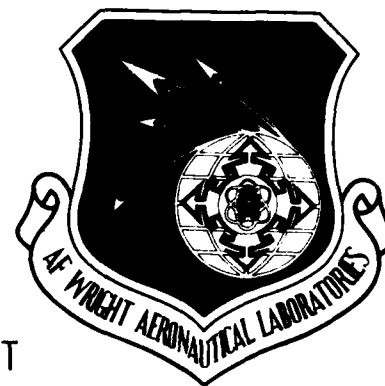
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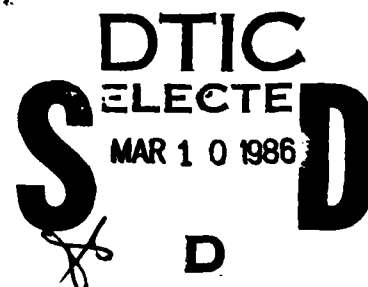
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A MICROCOMPUTER BASED SCANNING PRESSURE MEASUREMENT SYSTEM

Stephen F. Foley

Technology Branch
Turbine Engine Division



January 1986

FINAL REPORT FOR PERIOD JANUARY 1985 - AUGUST 1985

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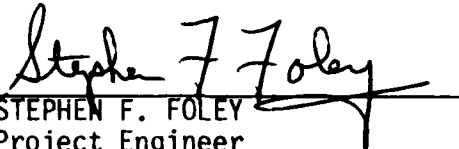
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This technical report has been reviewed and is approved for publication.


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<p>There is a requirement in the Air Force Wright Aeronautical Laboratory's Compressor Research Facility (CRF) for a multichannel pressure measurement system which can easily integrate into its present data acquisition system. The requirement for this system is based on a need for measurement of a large number of steady state pressures emanating from gas turbine engine compressor test vehicles.</p> <p>Implementation of such a system would greatly expand the data gathering capability of the CRF while vacating presently available channels for use in higher response pressure measurement applications. This report describes in detail the design and implementation of a scanning pressure measurement system which uses a personal computer as the controlling and data processing element.</p>				
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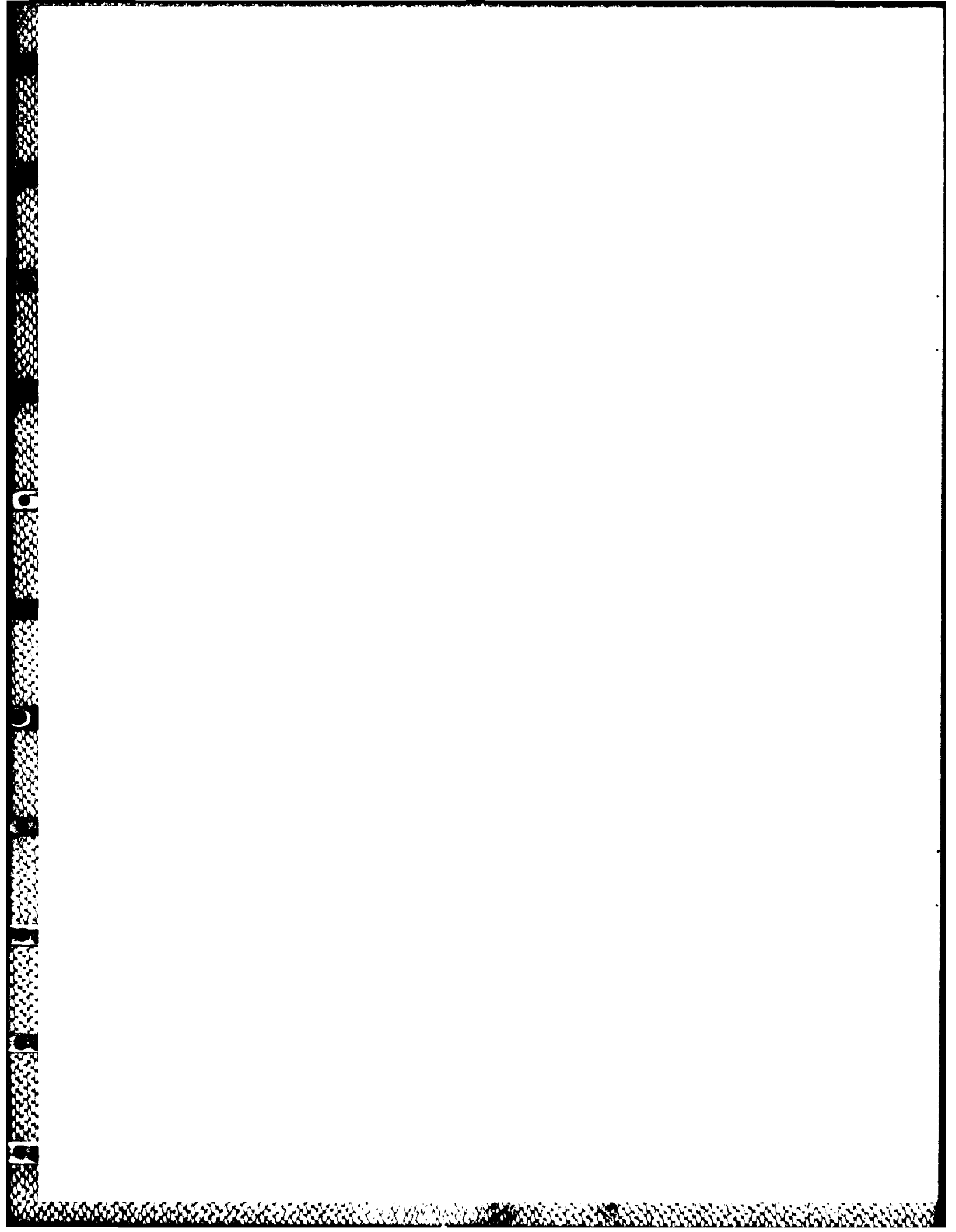
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FOREWORD

This report was prepared in the Technology Branch, Turbine Engine Division, Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio under Project No. 3066, Task No. 306617. This research was conducted during the period January 1985 through August 1985 with Stephen F. Foley as Project Engineer.



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SECTION I

INTRODUCTION

This report describes in detail a microcomputer based scanning pressure measurement system designed and implemented for use in jet engine compressor research. This pressure system utilizes a personal computer for control of the pressure measurement hardware and also for processing the acquired pressure signals. The flexibility and adaptability of this microcomputer system makes it ideal for applications which involve interfacing to the real world. The microcomputer with the addition of just a few plug-in circuit cards is programmed to control hardware, acquire and convert data, and transfer data to a larger data system.

The microcomputer is programmed in the basic computer language for simplicity. The code is written using a main control program which interfaces with the user and calls various subroutines to perform the tasks the user has selected.

The pressure subsystem which the microcomputer will control consists of six scanning pressure valves which essentially multiplex 48 input pressure ports into one pressure measurement port. This allows us to measure 48 pressures using only one pressure transducer. This type of system is useful for measuring only steady-state pressure signals since the scanning device is mechanical and has a slow sample rate.

The result of this thesis project is a multichannel pressure measurement system capable of acquiring calibrated pressure data from jet engine compressors and transferring this data across a link to a large centralized data collection system.

SECTION II

FUNCTIONAL REQUIREMENTS

Jet engine compressor researchers require hundreds of channels of pressure data to acquire an in-depth knowledge of what goes on in a compressor. Compressor research programs quite often have budgetary restrictions that are imposed on them. Therefore, the pressure hardware must accept a large number of pressure inputs in the range of 0 to 300 PSI using a minimum number of pressure transducers. These transducers must have a high degree of linearity and repeatability and a minimum of hysteresis. The analog signals from the pressure transducers must be amplified and converted into the digital domain for processing. A calibration standard traceable to the National Bureau of Standards (NBS) is required to calibrate each transducer on-line. These calibration signals are used in the process to convert raw counts into useable engineering units (PSI).

The processor must have the capability to process a large number of data channels and transfer the converted data to the facility data acquisition mini-computer via a RS-232 link. The processor must also have the ability to perform parallel I/O operations for any control/feedback paths which might be considered.

The software is written in Basic programming language and is required to control all of the data acquisition equipment including all pressure equipment and all interface hardware. The software is also required to perform on-line pressure calibrations by controlling the calibration equipment, reading and recording the data, and calculating new pressure coefficients for use in the engineering units conversion process. After all data is acquired, the pressure coefficients are applied, thus converting the data into engineering units.

The software is written for two modes of operation. The first being an off-line program for use in local display of pressure data and also debugging hardware and software problems. A printout is generated with converted data displayed and labeled. The second mode is an on-line program used when the facility is operational and the data is needed by the facility data acquisition minicomputer. In this mode the calibration, acquisition, and conversion routines are identical to the off-line mode except no printouts are generated and all data is passed across the link.

SECTION III

HARDWARE DESCRIPTION

This section describes the physical components of the scanning pressure measurement system. Figure 1 is an overall block diagram showing the actual system components and the interconnections between them. Most of the hardware shown is used because of its availability to this project. All of this hardware, except the TTL buffers, are commercially available products and no product is custom made.

1. MICROCOMPUTER

The microcomputer system used in this project is a Zenith Z-121 Desk Top Personal Computer. It contains 192 KBYTE of RAM, two 5 1/4 inch floppy disk drives, a 256 KBYTE memory expansion board, two RS-232 serial input/output ports, a Model 83A OKIDATA Printer, and a host of software support packages including Z-DOS (MS-DOS) and Z-Basic.

The Z-121 is designed around an IEEE-696 or S-100 bus. It has a five-slot card cage for S-100 based computer boards. Two slots are occupied by a disk controller card and a 256 KBYTE dynamic ram board. This leaves three slots for user defined S-100 cards. For this system a MUX/ADC board is needed along with a parallel I/O board. These boards will be described in detail later in this section.

The Z-100 features an automatic selection on bootup of either an 8-bit processor (Intel 8085) or 16-bit processor (Intel 8088) allowing use of software for either. For this project the 16-bit 8088 is used with the five megahertz clock for maximum computing power. For data transfer to and from the I/O Devices, an 8-bit word is used.

2. PRESSURE SUBSYSTEM

The scanning pressure system consists of six 48-port rotating valves which are connected together via a common stepping motor shaft and separate timing belts. The timing belts and common shaft to the stepping motor provide the synchronization needed to keep all valves on the same port at any point in time. A common port is

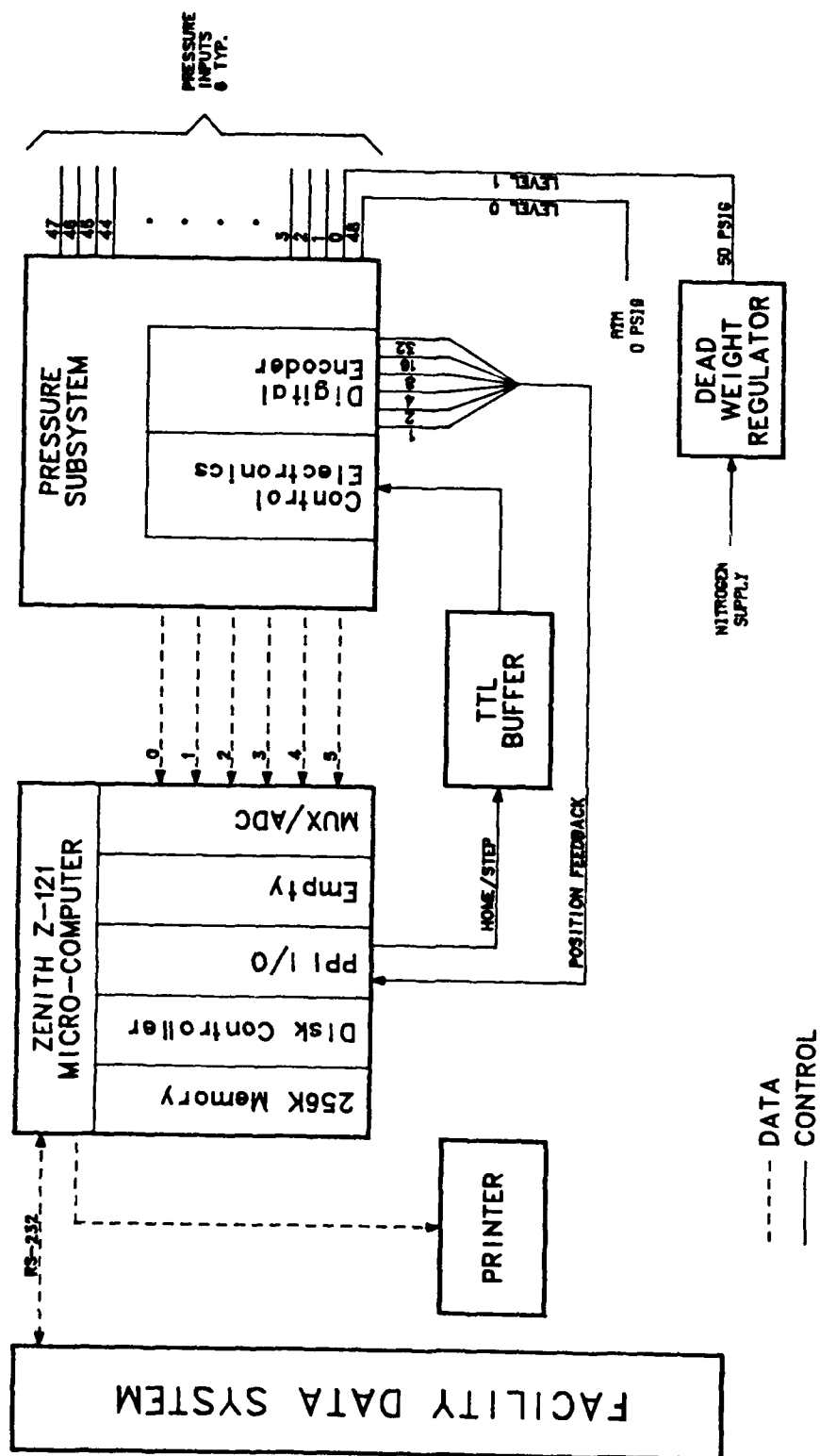


Figure 1. System Configuration

rotated in the counterclockwise direction accessing only one measurement port of the 48 at a time. An optical feedback digital encoder disk is also connected to the stepping motor shaft via a timing belt and provides a TTL output for each bit weight of 1, 2, 4, 8, 16, and 32 for conversion to the actual port number (Figure 2). The disc is binary coded from 1 through 48.

The scanning system has integral electronics for advancing the stepping motor in the counterclockwise direction. A simple contact closure is needed between the control step input and the system ground (called a step command) for the stepping electronics to advance the motor one port. Opening the contact and closing it again will result in another single step of the motor and so on. The contact closure required must be made for greater than five milliseconds. Time between commands must be greater than 30 milliseconds. Any times smaller than these may result in a command being missed by the electronics. Exact timing was not necessary as long as the time was greater than the minimum. The on and off times are obtained experimentally.

The home command is similar to the step command in that a contact closure is needed but this time across the control home input and the system ground. In this case with a single command the scanner electronics steps the scanning valve as many steps as needed to get the valves to port 48 or the "home" position. The contact closures are carried out using buffer transistors for protection of the computer hardware and will be addressed in the hardware description of the interfaces.

The scanning system works as follows: Pressures to be measured are connected to any of the 46 available ports (Ports 2 through 47) on anyone of the six valves. Port 48 and Port 1 on each valve are used for calibration pressures. A pressure transducer is connected to the common ports of all six valves. The outputs of these transducers are analog signals which are read by the microcomputer and converted into units of pressure. The scanning valves are then "homed" and "stepped" to Port 2. All six transducers are read, and the valve is stepped again. This process is repeated until all 46 ports are read.

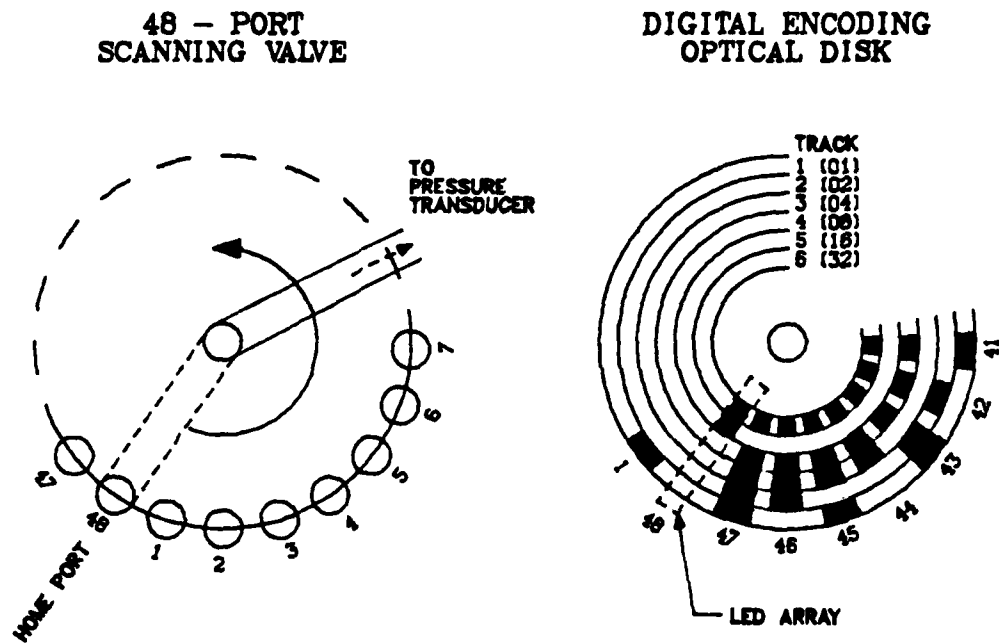


Figure 2. Scanning Valve with Digital Encoder

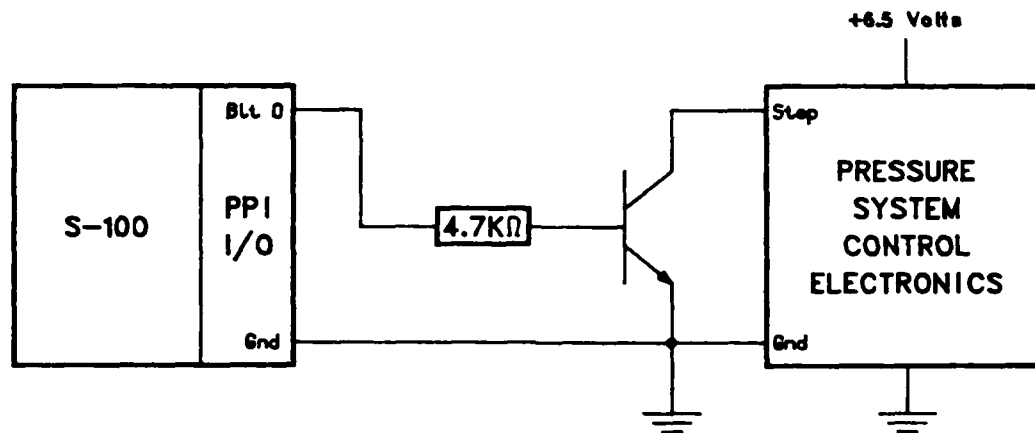


Figure 3. Pressure Subsystem Control Interface

The last interface is the pressure transducer to computer interface. The pressure transducers produce low level analog signals linearly proportional to the applied pressure. These signals are therefore amplified before going to the microcomputer. Upon arrival at the microcomputer, the signals are sampled by an S-100 analog multiplexer (MUX), controlled by software through the S-100 bus, thus directing them to the ADC one channel at a time. The MUX and ADC are on the same S-100 card and have a full scale input of ± 5 volts. The ADC is an 11-bit plus sign converter thus giving an output to the microcomputer data bus of ± 2048 counts for the ± 5 volt input. The resolution in volts per count is then calculated to be ± 0.002 . The worst case resolution in pressure, assuming a maximum applied pressure of 300 PSIG, is ± 0.146 PSI. The MUX/ADC throughput rate is 5000 samples per second per channel. This rate is more than adequate, remembering that the inputs are steady state in nature.

4. CALIBRATION

Pressure calibration is necessary to equate applied pressure to the count level seen by the microcomputer on a per channel basis. In other words, known pressures must be applied to the pressure transducers and read by the microcomputer. From this information, a slope and offset is calculated and used for each transducer when unknown pressure levels are applied. A two-point calibration is used for this

3. INTERFACES

There are five interfaces in this system. One is a parallel link to the printer which is Zenith supplied. Another is also Zenith supplied and is one of two RS-232 serial interfaces. This interface is used to transfer data from the micro-computer to the facility data system.

The third interface is a S-100 parallel input/output board which is inserted into the Zenith card cage. The device on the S-100 board used for parallel data transfer is an Intel 8255A Programmable Peripheral Interface (PPI). This chip has three 8-bit ports that are programmed as either an input or an output. Port A is chosen for input and Port B for output. Port C is not used in this application. Two bits of Port B are used for stepping and homing the scanning system. The outputs of the PPI are connected through a transistor buffer to protect the S-100 board from damage since it has to sink at least ten milliamps of current (Figure 3). Both the step and home commands are individually buffered. From the example shown in Figure 3, it can be seen that when Bit 0 is turned on, the step connection is effectively shorted to ground, thus stepping the scanning valve.

The scanning valve optical digital encoder is the fourth interface and has six output lines. Each output is a logic level signal which denotes a binary weighting. Output 1 through 6 corresponds to 2^0 through 2^5 , respectively. These signals are connected to Port A of the PPI and read by the Zenith Z-121. The appropriate outputs are turned on by the scanning system depending on which port it's currently sitting. The weightings are summed together to determine the port number. Since there are only 48 addressable ports on the scanning valve, not all of the possible 2^6 combinations of the encoder exist. Once Port 48 is read, the encoder starts over at Port 1.

SECTION IV

SOFTWARE DESCRIPTION

This section describes the functions of the software written exclusively for this pressure measurement system. As is the case in many system designs, the hardware is of a given configuration, and the software must be written to allow for hardware peculiarities. This system is no exception. The hardware interfacing requirements are reiterated to help the reader to understand why the software is implemented in a particular manner. Pressure measurement methodology and techniques are also described when needed to explain software design. All programs and subroutines are written in the Basic programming language and compiled for execution. See Appendix B for software programming flow charts.

1. I/O CONTROL

The MUX/ADC is controlled by writing to and reading from specific Zenith Z-121 I/O ports. The ports used are user selectable within the limitation of the Zenith Z-121 I/O configuration. Dip switches on the S-100 MUX/ADC board are set to select an 8-bit I/O mapped operation and starting port location. The starting location used is Port 16_D (or 10_H).

The generalized algorithm for sampling an A/D input is:

- 1) Set command port to desired options (gain select; auto sequence or load enable; external strobe select; interrupt enable for Timer 1, 2; A/D overrun or A/D done; and wait function enable). Write Port 16.
- 2) Set multiplexer address to desired input line (0 through 8). Write Port 18.
- 3) Start conversion. Write anything to Port 20.
- 4) Read status of A/D. This is Bit 7 and is designated "A/D done" and will become a "1" when the conversion is complete. Read Port 16.
- 5) Read low 8 bits of A/D. Read Port 18.
- 6) Read high 8 bits of A/D. Read Port 20.

calibration scheme. The transducers used in this system are extremely linear, repeatable, and have no hysteresis. Under this condition and from years of experience with these transducers, a two point calibration is justified. Applying the two known pressures and taking a reading for each gives us two equations with two unknowns from which a slope term and an offset term are calculated. This process is done for each and every pressure transducer in the system.

Calibration Pressure Level 2 comes from an NBS traceable dead weight pressure regulator. These devices are at least an order of magnitude better in accuracy as the pressure transducers used. This pressure is applied to all six valves at Port 1. All inputs to Port 48 (home port) are at ambient pressure as are the reference sides of each transducer. This results in an actual pressure of 0 PSID across the transducer. With zero pressure at all ports numbered 48 and a known higher pressure at all ports numbered 1, each pressure transducer has its required calibration pressures. Homing the scanning valves applies the Level 1 calibration pressure to all transducers and stepping the valves one time applies the Level 2 calibration pressure to all the transducers. All other Ports, 2 through 47, on all six valves are used for user defined pressure measurement.

5. FACILITY DATA SYSTEM

The Compressor Research Facility is used to develop compressors in a laboratory environment to prevent costly rebuilds which occur in full-scale engine development. The facility is equipped to handle large quantities of pressure, temperature, vibration, and blade clearance measurements. All data is acquired by a minicomputer network and transferred to an IBM 4341 mainframe processor for conversion, display, and storage.

The minicomputer network was not accessible during the development of this scanning system because of on-going compressor testing so an alternative means for accepting the data from the Zenith microcomputer was used. The data is now passed to a Lear Siegler ADM-31 smart terminal through the Zenith's communication port. The data is sent at 9600 baud and displayed on the ADM's CRT. This is adequate to prove that data transfer is possible from the Zenith microcomputer. The communication to the facility network will be accomplished at a later date.

The Zenith Basic code for a typical A/D input on Channel 3 looks like this:

10 out(16), 4	Sets load enable
20 out(18), 3	Sets input MUX to Channel 3
30 out(20), 0	Starts A/D conversion
40 if inp(16)/128=0 goto 40	Checks for "A/D done"
50 A = inp(20)	Inputs high byte
60 B = inp(18)	Inputs low byte

The high byte value is then multiplied by 256 and added to the value of the low byte to attain the count value of the A/D conversion.

The S-100 parallel I/O board is also controlled by writing to and reading from specific Zenith Z-121 I/O ports. The port selected for this board is Port 40_0 (or 28_H).

The general algorithm for sending or receiving data is:

- 1) Set command port to desired options (mode select enable; simple I/O, strobed I/O or 8-bit bidirectional; bus Port A, B, or C selection of input or output). Write Port $2F_H$.
- 2) Output 8-bit data value to desired port (A, B, or C). Write Port $2C_H$, $2D_H$, or $2E_H$, respectively.

- or -

- 2) Input 8-bit data value from desired port (A, B, or C). Read Port $2C_H$, $2D_H$, or $2E_H$, respectively.

The choice of input or output for any port (A, B, or C) is made when the command port is sent the control data word. A typical Basic program for using the parallel I/O board looks like this:

Input

10 out&H2F,&H82

Sets Port A to
output, B to
input, C to
output

20 A = inp(&H2D)

Inputs 8-bits from Port B

Output

10 out&H2F,&H82

Sets Port A to
output, B to
input, C to
output

20 out&H2C,&H02

Sets Bit 2 on
Port A

2. SCANNING VALVE CONTROL

The scanning valve (SV) subsystem has on board electronics to sense contact closures for control of its stepping and homing functions. A step contact closure causes the valves to be advanced one port (or step) in the counterclockwise rotational direction. This system is a unidirectional stepping motor system. A home contact closure causes the SV to rotate to a manufacturer determined fixed port called the "home" port. This port is always Port 48. This homing function provides extremely fast slewing of the valves.

When a step of the SV is requested, the step counter is incremented and the step bit on Port A of the programmable peripheral interface (PPI) is set. This causes a contact closure on the input to the SV step circuit. This output must remain high for a minimum of 5 milliseconds. It is then turned off and must remain off at least 30 milliseconds before another step command can occur. Missed steps may be the result if insufficient delay times are used. The optical binary encoder is then read from Port B of the PPI and converted into a decimal number. This actual port number is compared to the step counter (desired port number). If equal, the step has been successful. Otherwise, a stepping error has occurred. If the desired port is greater than the actual port, it tries to step the SV to the desired port. If the desired port is less than the actual port, it homes the SV and then steps to the desired port. Remember, the home command moves the valves much quicker than successive stepping.

The number of tries to accomplish a successful step is limited to three. After three attempts, an error flag is set and control is returned to the calling program which stops the process.

When a home command is given, the home bit on Port A of the PPI is set and then reset. The same restriction on the timing of the contact closure that was used on the step command still applies here. After a sufficient time, the binary optical encoder is read. If the port read is the home port (48), then the home command was successful. Otherwise, a homing error has occurred. This procedure is tried three times and, if unsuccessful, an error flag is set and control is returned to the calling program which stops the process.

3. CALIBRATION

In order to interpret the output signal of a pressure transducer, the relationship between the pressure applied and the output signal must be established. This is done by applying a known pressure to the transducer and measuring its output. At least two pressure versus output points must be taken in order to establish the relationship. More points are needed if this relationship is not linear or has hysteresis. From past experience, these pressure transducers and system components were found to be extremely linear, repeatable, and with negligible hysteresis. This

is the reason a two-point calibration was used as the means for acquiring the pressure coefficient data.

For the calibration, the two known pressures are connected to each valve. Each home port is supplied the Level 1 pressure of 0 PSIG (atmospheric) and each Port 1 is supplied the Level 2 pressure of 50 PSIG. This provides the two-point calibration necessary for each valve and associated transducer.

The pressure transducer outputs are fed into individual amplifiers to raise the voltage levels thus improving the signal-to-noise ratio. The amplifier outputs are then cabled to the input of an S-100 multiplexer/analog-to-digital converter board. These amplified transducer signals are then read by selecting the appropriate multiplexer channel and starting the analog-to-digital converter.

When a pressure calibration (PCAL) is requested, a home command is issued, thereby causing the Level 1 pressure to be applied to all six transducers' input. Then transducer one is scanned 30 times and the data is averaged and stored. According to Abernethy and Thompson (Reference 1), for this type of measurement, 30 is a statistically sufficient number of samples to provide a good estimate. Each of the remaining five transducers are then scanned in the same manner. The SV is then stepped to Level 2 pressure ports, which have the 50 PSIG pressure applied to them, and the scanning repeats itself.

We now have enough data to determine the pressure-transducer output relationship. The transducer output is in counts since we have converted the analog signal to the digital domain. Full-scale input is 2048 counts. The slope (m) and offset (b) for each transducer relationship is calculated using known formulas.

$$Y_1 = mX_1 + b$$

$$Y_2 = mX_2 + b$$

Where Y_1 = Pressure Level 1
 Y_2 = Pressure Level 2
 X_1 = Counts at Level 1
 X_2 = Counts at Level 2

CALIBRATION DATA

LEVEL1	LEVEL2
-2	715
-1	530
0	1057
-121	2024
-125	2008
-119	2018

CALIBRATION COEFFICIENTS

SLOPE	OFFSET
0.0697	0.1395
0.0942	0.0942
0.0473	0.0000
0.0233	2.8205
0.0234	2.9301
0.0234	2.7843

CALIBRATION DATA

LEVEL1	LEVEL2
-2	718
-1	530
0	1057
-122	2024
-125	2008
-122	2018

CALIBRATION COEFFICIENTS

SLOPE	OFFSET
0.0694	0.1389
0.0942	0.0942
0.0473	0.0000
0.0233	2.8425
0.0234	2.9301
0.0234	2.8505

Figure 4. Typical Calibration Raw Data and Coefficients

Since we have two equations and two unknowns, we can solve them simultaneously for the slope:

$$m = (Y_1 - Y_2)/(X_1 - X_2)$$

Once the slope is determined, the offset is calculated by substituting the slope equation into one of the original equations:

$$b = Y_1 - mX_1$$

The raw count data for Level 1 and Level 2 and the pressure coefficients are written to the line printer (Figure 4). The pressure coefficients determined previously are stored in memory for later use.

If at anytime during the calculations, the difference between the counts read at Level 1 and the counts read at Level 2 is zero, an error flag is set and control is returned to the calling routine. This error indicates that there is a hardware problem in the pressure system or in the transducer signal path.

4. DATA ACQUISITION

Since Port 48 and Port 1 on each valve are used for calibration, they are obviously not available for turbine engine compressor pressure inputs. This leaves Ports 2 through 47 (46 total) on each valve for a total of 276 measurement ports.

When a scan of data is requested, the SV is homed and stepped past the first two calibration ports to ports numbered 2. The data is then acquired for each transducer 30 times, averaged, and stored in a buffer which is dimensioned 46 by 6. The SV is then stepped and the process is repeated until all 46 ports on every valve have been addressed. Control is then passed to the calling routine.

7. OFF-LINE CONTROL PROGRAM

Many times in the course of running a turbine engine compressor test program, a requirement is given to measure pressures in the test cell area which are not from the compressor. These include a variety of pressures from the compressor support systems such as the test article lubrication systems, the water cooling system, or even the hydraulic actuation system. This is the major reason the off-line program was written. A side benefit, of course, is the ability to check the system for operational ability by having a means to see the data after it has been acquired and converted. It also permits the inspection of the calibration coefficients calculated along with the raw pressure data. In contrast, the on-line control program acquires and converts the data and then directly sends it to the ADM-31 terminal. No printout or display of any kind is generated in order to maximize the data throughput rate of the system.

The off-line program begins by dimensioning the data arrays and setting the error flag word (IERR) to value of zero indicating a no-fault status. The optical digital encoder is then read and converted. This value is placed into the step counter as an initial value for error checking of the pressure subsystem stepping ability. If no errors are detected on reading the encoder, the microprocessor now knows what port the scanning valves are on. A call to the step subroutine increments the step counter, thereby producing the desired port number.

The scanning valve is then stepped and its encoder is read. If the step counter is not equal to the encoder value, a step error has occurred. A home command is also executed. If the port read on the encoder is not 48, then a home error has occurred.

These procedures are needed to verify the physical movement of the scanning valves before data can be acquired. If successful, a pressure calibration is automatically performed because without pressure coefficients this system is virtually useless. Therefore, no operator interaction is called for until the first calibration is finished and raw data, along with pressure coefficients, are printed. At that time, the operator is given choices of doing another calibration, quitting, or moving on to perform a scan of all pressure ports. Answers to these questions that are not "yes" or "no" are invalid and must be entered again.

5. DATA CONVERSION

The data acquired by the acquisition software is in digital counts from the analog-to-digital converter. An engineering units conversion is made on the data in order to present the data in units of pressure (PSIG). This is accomplished by recalling the calibration coefficients previously calculated. By multiplying the slope term by the counts read and adding the offset term, the data values are converted to units of pressure. After all 276 conversions are finished, control is passed to the calling routine.

6. DATA TRANSFER

For the checkout of the Zenith to ADM-31 RS-232 communication link, the output of the Zenith RS-232 port is attached to a null modem and then into an ADM-31 terminal. The Zenith RS-232 auxiliary port was configured in the following manner:

- Serial data stream
- 9600 baud
- No handshaking
- One stop bit
- Odd parity
- Seven bit data word
- Zero pad characters

The 9600 baud is a limit of the ADM-31. The Zenith can handle a data rate up to 38.5K baud. The facility data computer can also handle the 38.5K baud so this rate will be used during the actual operation for transfer of the data to the facility data computer. A communication file (Com1) was defined for 9600 baud, odd parity, and seven bit data words. This file then is opened and defined as File No. 1. The converted data is then sent to the sequential communication File No. 1. The ADM-31 immediately began displaying the acquired data in a serial manner and at 9600 baud. Program control was then returned to the calling program.

At a later time when the data is transferred to a computer, a more sophisticated communication handler will have to be written. Handshaking will be needed to assure the entire data file is passed. This handler is entirely machine dependent.

	1	2	3	4	5	6
2.00	0.29	-0.10	0.02	-0.09	0.00	-0.06
3.00	-0.07	-0.09	0.02	-0.08	0.00	-0.05
4.00	-0.07	-0.09	0.02	-0.09	0.00	-0.07
5.00	-0.07	-0.09	0.02	-0.09	0.00	-0.04
6.00	-0.08	-0.08	0.02	-0.09	0.00	-0.06
7.00	-0.07	-0.08	0.01	-0.09	0.00	-0.07
8.00	-0.07	-0.08	0.02	-0.09	0.00	-0.07
9.00	-0.08	-0.06	0.02	-0.09	0.00	-0.07
10.00	-0.07	-0.06	0.02	-0.08	0.00	-0.07
11.00	-0.07	-0.07	0.01	-0.08	0.00	-0.06
12.00	-0.08	-0.06	0.02	-0.09	0.00	-0.06
13.00	-0.07	-0.06	0.01	-0.09	0.00	-0.06
14.00	-0.07	-0.06	0.02	-0.08	0.00	-0.07
15.00	-0.08	-0.05	0.02	50.06	0.00	-0.07
16.00	-0.08	-0.04	0.01	0.05	0.00	-0.06
17.00	-0.07	0.01	0.02	-0.05	0.00	-0.07
18.00	-0.07	0.00	0.02	-0.07	0.00	-0.07
19.00	-0.08	-0.04	0.02	-0.08	0.00	-0.07
20.00	-0.07	50.09	0.02	-0.09	0.00	-0.06
21.00	-0.07	-0.06	0.02	-0.08	0.00	-0.07
22.00	-0.08	-0.09	0.01	-0.09	0.00	-0.07
23.00	-0.07	-0.03	0.02	-0.08	0.00	-0.06
24.00	-0.07	-0.08	0.02	-0.08	0.00	-0.06
25.00	-0.07	-0.09	50.05	-0.08	0.00	-0.06
26.00	-0.08	-0.08	0.02	-0.09	0.00	-0.07
27.00	-0.07	-0.09	0.02	-0.09	0.00	-0.06
28.00	-0.07	-0.07	0.01	-0.09	0.00	-0.07
29.00	-0.07	-0.07	0.01	-0.09	0.00	-0.06
30.00	-0.07	-0.07	0.02	-0.09	0.00	-0.07
31.00	-0.07	-0.07	0.02	-0.08	0.00	-0.07
32.00	-0.08	-0.06	0.02	-0.09	0.00	-0.06
33.00	-0.07	-0.06	0.02	-0.08	0.00	-0.07
34.00	-0.08	-0.05	0.02	-0.09	0.00	-0.07
35.00	-0.07	-0.04	0.02	-0.09	0.00	-0.07
36.00	-0.07	-0.04	0.02	-0.09	0.00	-0.06
37.00	49.97	-0.05	0.02	-0.09	0.00	-0.07
38.00	0.07	-0.05	0.02	-0.09	0.00	-0.07
39.00	-0.07	-0.05	0.02	-0.09	50.05	-0.07
40.00	-0.07	-0.04	0.02	-0.09	0.00	-0.06
41.00	-0.07	-0.04	0.02	-0.09	0.00	-0.07
42.00	-0.07	-0.05	0.02	-0.08	0.00	-0.07
43.00	-0.07	-0.04	0.01	-0.09	0.00	-0.07
44.00	-0.07	-0.05	0.02	-0.08	0.00	-0.07
45.00	-0.08	-0.03	0.02	-0.08	0.00	-0.07
46.00	-0.08	-0.04	0.02	-0.09	0.00	-0.06
47.00	-0.08	-0.04	0.01	-0.09	0.00	50.05

Figure 5. Typical Pressure Data Output Listing

Continuing on will result in a call to the scan subroutine which will acquire averaged count values for all 276 pressure ports. The data is then converted and listed on the system printer along with the valve number and its associated port number (Figure 5).

At this point another scan of data can be taken or a pressure calibration can be performed. If neither is wanted, the program is terminated.

8. ON-LINE CONTROL PROGRAM

The on-line program performs many of the same tasks as the off-line version but with differences in the transmission of the converted data. The hardware checkout of the step and home commands and the pressure calibration are exactly the same. The scanning of the pressure transducers and the data conversion are also the same. The output to the line printer does not exist, however. It has been replaced with a subroutine which transfers the data across an RS-232 link to a Lear Siegler ADM-31 smart terminal for local display. This method represents the data transfer to another computer. During a test (on-line) the microcomputer based system is continually scanning the input pressure ports, converting the data into units of pressure, and passing the data across the link.

SECTION V

SUMMARY AND CONCLUSIONS

The scanning valve system was configured and operated with little difficulty. Some of the problems encountered included command timing, compilation, and valve leaks.

The command timing problem involved the step and home commands given to the scanning valve electronics using Basic OUT commands. These OUT commands are addressed to a specific Zenith Z-121 port which addresses a port on a programmable peripheral interface. To step the valve, a particular bit is turned on and then off, giving the scanning valve electronics a pulse. If multiple step commands are given, the scanning valve fails to see all the step command pulses resulting in missed steps. In other words, the on-off toggling program is running faster than the scanning valve's mechanical stepping rate. The valve electronics needed a 5 milliseconds pulse width and 30 milliseconds between pulses. To handle this requirement, several do-nothing or delay loops had to be implemented in software. The exact timing is determined by trial and error. The delay times were increased until the scanning valve was stepping correctly 100% of the time. The duty cycle of the command pulses is set at one-sixth, which corresponds to the 5 milliseconds on and 30 milliseconds off requirement. This method is only one of several possible solutions including a hardware timer option.

The above solution worked quite well until the multiple sampling of each transducer was implemented. Taking 30 samples of each transducer to produce a good average slowed the whole data acquisition and stepping process to an unacceptable level. It took three to four minutes for a complete scan of all 46 ports. This unacceptable time brought on the requirement to compile the programs instead of running them through the interpreter. The first time the compiled program was used, the scanning valve again had stepping problems. This, of course, is due to the faster execution times of a compiled program. Again, the timing for the scanning valve had to be determined by trial and error but this time considering the faster program execution times. The actual program delays loops increased by approximately 20 times but the actual delay times remained the same. With this program modification, the scanning valve steps were error free 100% of the time.

The only other problem encountered was an apparent leak in the internal portion of Valve No. 1. The leak caused a small error in determining the calibration coefficients for that valve and consequentially a small error in measurement of Ports 2 through 47. The valves use oiled seals for maintaining pressures and are likely candidates for the problem.

In conclusion, this system is a viable alternative to the more costly single-transducer-per-channel systems used for steady state pressure measurement. It can be affordably configured and used. The software written is easily understood by even the most inexperienced Basic programmer. The hardware is completely available to anyone in industry or government. The system is accurate and can be easily expanded to handle at least twice the current number of channels. Overall, this scanning pressure measurement system will be an asset to the CRF in many years to come and has met all requirements needed to provide turbine engine compressor pressure data.

APPENDIX A
SOFTWARE LISTINGS

```

10 ' $TITLE: 'OFFLINE PROGRAM' $SUBTITLE: 'WRITTEN BY S.FOLEY 10APR85'
20 REM -----
21 DIM CALP(2,6),CALD(2,6),CALC(2,6),SCAN(46,6)
30 IERR=0
40 GOSUB 2700: REM **** CALL TO BINP SUBROUTINE ****
60 IF IERR=0 THEN GOTO 450
80 ISTEP=IPORT
90 PRINT "SCANIVALVE OFFLINE PROGRAM--- WRITTEN BY S.FOLEY 10APR85"
100 GOSUB 1000: REM **** CALL TO STEP SUBROUTINE ****
110 IF IERR=0 GOTO 450
120 PRINT "STEP COMMAND WORKS"
130 GOSUB 1290: REM **** CALL TO HOME SUBROUTINE ****
140 IF IERR=0 GOTO 450
150 PRINT "HOME COMMAND WORKS"
160 PRINT "ATTEMPTING A PRESSURE CALIBRATION"
170 GOSUB 2000: REM **** CALL TO PCAL SUBROUTINE ****
180 IF IERR=0 GOTO 450
190 PRINT "PCAL SUCCESSFUL"
200 PRINT "WANT ANOTHER PCAL ( Y OR N )"
210 J$=INPUT$(1):IF J$="Y" THEN GOTO 170
220 IF J$="N" THEN GOTO 250
230 PRINT "ANSWER ( Y OR N )"
240 GOTO 210
250 PRINT "CONTINUE ( Y OR N )"
260 J$=INPUT$(1):IF J$="Y" THEN GOTO 300
270 IF J$="N" THEN GOTO 291
280 PRINT "ANSWER ( Y OR N )"
290 GOTO 250
291 PRINT "OK --- PROGRAM TERMINATED":STOP
300 PRINT "BEGIN SCAN"
310 GOSUB 3000: REM **** CALL TO SCAN SUBROUTINE ****
311 IF IERR=0 GOTO 450
315 GOSUB 3500: REM **** CALL TO CONV SUBROUTINE ****
319 LPRINT " ";LPRINT " "
320 LPRINT USING "*****";0,1,2,3,4,5,6:LPRINT " ";LPRINT " "
321 FOR I=1 TO 46
322 II=I+1
324 LPRINT USING "*****.##";II,SCAN(I,1),SCAN(I,2),SCAN(I,3),SCAN(I,4),SCAN(I,5),SCAN(I,6)
325 NEXT I
330 PRINT "SCAN COMPLETE WANT ANOTHER ( Y OR N )"
340 J$=INPUT$(1):IF J$="Y" THEN GOTO 300
350 IF J$="N" THEN GOTO 380
360 PRINT "ANSWER ( Y OR N )"
370 GOTO 340
380 PRINT "WOULD YOU LIKE A PCAL ANSWER ( Y OR N )"
390 J$=INPUT$(1):IF J$="Y" GOTO 160
400 IF J$="N" THEN GOTO 430
410 PRINT "ANSWER ( Y OR N )"
420 GOTO 390
430 PRINT "YOU ARE OBVIOUSLY FINISHED FOR NOW--- BYE"
440 STOP
449 REM
450 REM **** ERROR LOGGING ****
451 REM
460 IF IERR=1 THEN PRINT "ERROR IN STEPPING SCANIVALVE"
470 IF IERR=2 THEN PRINT "ERROR IN HOMING SCANIVALVE"
480 IF IERR=3 THEN PRINT "ERROR IN READING PORT FEEDBACK ENCODER"
490 IF IERR=4 THEN PRINT "INDETERMINANT SLOPE---DWT NOT UP YET?"
500 STOP

```

Figure A.1. Off-Line Control Program

```

10 REM MAIN ONLINE PROGRAM
20 REM -----
21 DIM CALP(2,6),CALD(2,6),CALC(2,6),SCANDAT(46,6)
30 IERR=0
40 GOSUB 2700:REM **** CALL TO BINP SUBROUTINE ****
60 IF IERR()=0 THEN GOTO 450
80 ISTEP=IPOINT
90 PRINT "SCANIVALVE ONLINE PROGRAM--- WRITTEN BY S.FOLEY 16APR85"
100 GOSUB 1000:REM **** CALL TO STEP SUBROUTINE ****
110 IF IERR()=0 GOTO 450
120 PRINT "STEP COMMAND WORKS"
130 GOSUB 1290:REM **** CALL TO HOME SUBROUTINE ****
140 IF IERR()=0 GOTO 450
150 PRINT "HOME COMMAND WORKS"
160 PRINT "ATTEMPTING A PRESSURE CALIBRATION"
170 GOSUB 2000:REM **** CALL TO PCAL SUBROUTINE ****
180 IF IERR()=0 GOTO 450
190 PRINT "PCAL SUCCESSFUL"
200 PRINT "WANT ANOTHER PCAL ( Y OR N )"
210 J$=INPUT$(1):IF J$="Y" THEN GOTO 170
220 IF J$="N" THEN GOTO 250
230 PRINT "ANSWER ( Y OR N )"
240 GOTO 210
250 PRINT "CONTINUE ( Y OR N )"
260 J$=INPUT$(1):IF J$="Y" THEN GOTO 300
270 IF J$="N" THEN GOTO 291
280 PRINT "ANSWER ( Y OR N )"
290 GOTO 250
291 PRINT "OK --- PROGRAM TERMINATED":STOP
300 PRINT "BEGIN SCAN"
310 GOSUB 3000:REM **** CALL TO SCAN SUBROUTINE ****
311 IF IERR()=0 GOTO 450
315 GOSUB 3500:REM **** CALL TO CONV SUBROUTINE ****
319 PRINT "TRANSFERING DATA TO DATA ACQUISITION COMPUTER"
320 GOSUB 4000:REM **** CALL TO XFER SUBROUTINE ****
325 IF IERR()=0 GOTO 450
330 GOTO 300
450 REM **** ERROR LOGGING ****
460 IF IERR=1 THEN PRINT "ERROR IN STEPPING SCANIVALVE"
470 IF IERR=2 THEN PRINT "ERROR IN HOMING SCANIVALVE"
480 IF IERR=3 THEN PRINT "ERROR IN READING PORT FEEDBACK ENCODER"
490 IF IERR=4 THEN PRINT "INDETERMINANT SLOPE---DWT NOT UP YET?"
500 IF IERR=5 THEN PRINT "ERROR IN TRANSFER TO DATA COMPUTER"
510 STOP

```

Figure A.2. On-Line Control Program

```

1000 REM      SUBROUTINE STEP
1001 REM -----
1010 ISTERR=0
1020 ISTEP=ISTEP+1;IF ISTEP=49 THEN ISTEP=1
1030 OUT &H2F,&H82
1040 OUT &H2C,4
1041 ISTE=50
1042 ISTE=ISTE-1;IF ISTE>0 GOTO 1042
1050 OUT &H2F,&H82
1060 OUT &H2C,0
1061 ISTE=300
1062 ISTE=ISTE-1;IF ISTE>0 GOTO 1062
1070 GOSUB 2700:REM **** CALL TO BINP SUBROUTINE ****
1080 IF IERR<>0 THEN RETURN
1110 IF IPORT=ISTEP THEN RETURN
1120 ISTERR=ISTERR+1;IF ISTERR>3 GOTO 1260
1130 IF IPORT>ISTEP GOTO 1150
1135 IVAL=ABS(ISTEP-IPORT)
1140 GOTO 1180
1141 ITSTEP=ISTEP
1150 GOSUB 1290:REM **** CALL TO HOME SUBROUTINE ****
1151 ISTEP=ITSTEP
1160 IF IERR>3 THEN RETURN
1170 IVAL=ISTEP
1180 FOR I=1 TO IVAL
1190 OUT &H2F,&H82
1200 OUT &H2C,4
1201 ISTE=50
1202 ISTE=ISTE-1;IF ISTE>0 GOTO 1202
1210 OUT &H2F,&H82
1220 OUT &H2C,0
1225 ISTE=300
1230 ISTE=ISTE-1;IF ISTE>0 GOTO 1230
1240 NEXT I
1250 GOTO 1070
1260 IERR=1:RETURN

```

Figure A.3. Scanning Valve Step Subroutine

```
1290 REM  SUBROUTINE  HOME
1291 REM  -----
1300 IHERR=0
1310 OUT &H2F,&H82
1320 OUT &H2C,2
1321 IHTIME=50
1322 IHTIME=IHTIME-1:IF IHTIME>0 GOTO 1322
1330 OUT &H2F,&H82
1340 OUT &H2C,0
1341 IHTIME=9000
1350 IHTIME=IHTIME-1:IF IHTIME>0 GOTO 1350
1360 GOSUB 2700:REM **** CALL TO BINP SUBROUTINE ****
1370 IF IERR<>0 THEN RETURN
1380 IF IPORT=48 THEN GOTO 1401
1390 IHERR=IHERR+1:IF IHERR>3 THEN GOTO 1403
1400 GOTO 1310
1401 ISTEP=48
1402 RETURN
1403 IERR=2:RETURN
```

Figure A.4. Scanning Valve Homing Subroutine

```

2000 REM      SUBROUTINE      PCAL
2001 REM -----
2020 CALP(1,1)=0:CALP(1,2)=0:CALP(1,3)=0:CALP(1,4)=0:CALP(1,5)=0:CALP(1,6)=0
2030 CALP(2,1)=50:CALP(2,2)=50:CALP(2,3)=50:CALP(2,4)=50:CALP(2,5)=50
2040 CALP(2,6)=50
2100 GOSUB 1290:REM ***** CALL TO HOME SUBROUTINE *****
2110 IF IERR()=0 THEN RETURN
2200 K=1
2300 FOR J= 0 TO 5
2310 OUT 16,4
2320 OUT 18,J
2330 OUT 20,0
2340 IF INP(16)/128=0 GOTO 2340
2350 JJ=J+1
2360 CALD(K,JJ)=256*INP(20)+INP(18)
2370 IF CALD(K,JJ)>32767 THEN CALD(K,JJ)=(65537!-CALD(K,JJ))*-1
2380 NEXT J
2385 IF K=2 GOTO 2420
2390 GOSUB 1000:REM ***** CALL TO STEP SUBROUTINE *****
2395 IF IERR()=0 THEN RETURN
2400 K=2
2410 GOTO 2300
2420 REM ***** ALL CAL DATA IS NOW ACQUIRED LET THE PROCESSING BEGIN *****
2425 FOR L=1 TO 6
2427 LPRINT CALD(1,L),CALD(2,L):NEXT L
2430 FOR I=1 TO 6
2435 IF (CALD(2,I)-CALD(1,I))=0 THEN GOTO 2466
2440 CALC(1,I)=(CALP(2,I)-CALP(1,I))/(CALD(2,I)-CALD(1,I))
2450 CALC(2,I)=CALP(1,I)-CALC(1,I)*CALD(1,I)
2455 LPRINT CALC(1,I),CALC(2,I)
2460 NEXT I
2465 RETURN
2466 IERR=4
2470 RETURN

```

Figure A.5. Pressure Calibration Subroutine

```
2700 REM  SUBROUTINE  BINP
2710 REM  -----
2720 OUT &H2F,&H02
2730 AINP=INP(&H2D)
2740 IPORT=INT(63-AINP/4+.5)
2750 IF IPORT>48 OR IPORT<0 THEN IERR=3
2760 RETURN
```

Figure A.6. Digital Encoder Input Subroutine

```

3000 REM SUBROUTINE SCAN
3010 REM -----
3020 FOR I=1 TO 46
3030 FOR J=1 TO 6
3040 SCANDAT(I,J)=0
3050 NEXT J
3060 NEXT I
3070 GOSUB 1290:REM **** CALL TO HOME SUBROUTINE ****
3080 IF IERR()=0 THEN RETURN
3090 GOSUB 1000:REM **** CALL TO STEP SUBROUTINE ****
3100 IF IERR()=0 THEN RETURN
3110 GOSUB 1000:REM **** CALL TO STEP SUBROUTINE ****
3120 IF IERR()=0 THEN RETURN
3130 FOR I=1 TO 46
3140 FOR J=1 TO 6
3150 JJ=J-1
3160 FOR K=1 TO 30
3170 OUT 16,4
3180 OUT 18,JJ
3190 OUT 20,0
3200 IF INP(16)/128=0 THEN GOTO 3200
3210 TEMP=256*INP(20)+INP(18)
3211 IF TEMP>32767 THEN TEMP=(65537!-TEMP)*-1
3220 SCANDAT(I,J)=SCANDAT(I,J)+TEMP
3230 NEXT K
3240 SCANDAT(I,J)=SCANDAT(I,J)/30
3250 NEXT J
3260 GOSUB 1000:REM **** CALL TO STEP SUBROUTINE ****
3270 NEXT I
3280 RETURN

```

Figure A.7. Valve Port Scanning Subroutine

```

4000 REM $TITLE:'SUBROUTINE XFER'
4010 REM -----
4040 FOR I=1 TO 46
4050 FOR J=1 TO 6
4060 PRINT #1,SCANDAT(I,J),CHR$(10),CHR$(13)
4070 NEXT J
4080 NEXT I
4090 PRINT "DATA HAS BEEN SUCCESSFULLY TRANSFERRED "
4100 RETURN

```

Figure A.8. Data Transfer Subroutine

```
3500 REM  SUBROUTINE  CONV
3510 REM  -----
3520 FOR I=1 TO 46
3530 FOR J=1 TO 6
3540 SCANDAT(I,J)=SCANDAT(I,J)+CALC(1,J)+CALC(2,J)
3550 NEXT J
3560 NEXT I
3570 RETURN
```

Figure A.9. Data Conversion Subroutine

APPENDIX B
SOFTWARE PROGRAMMING FLOW CHARTS

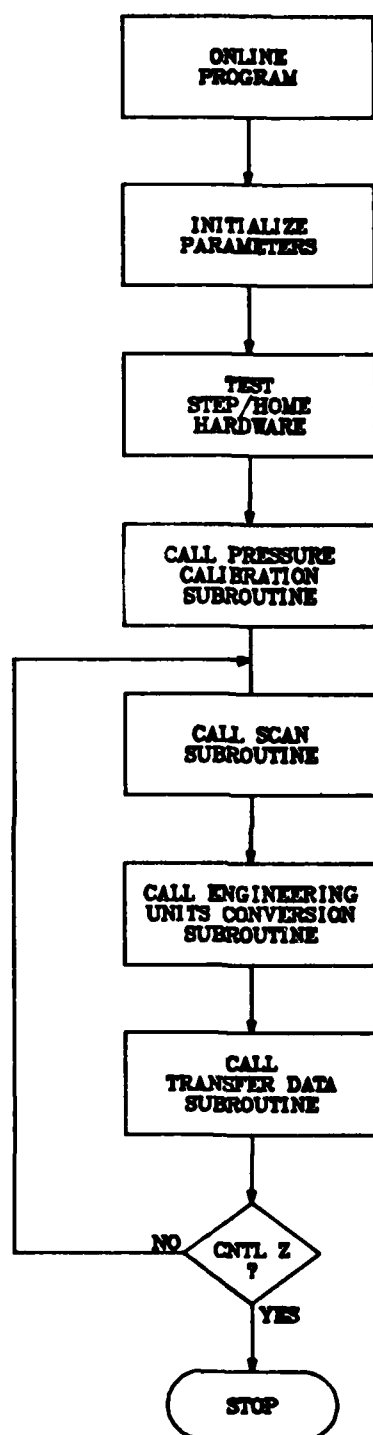


Figure B.1. On-Line Control Program Flow Chart

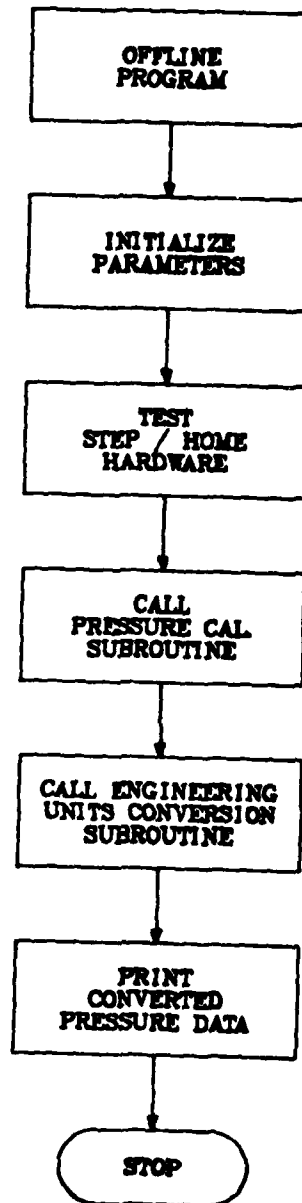


Figure B.2. Off-Line Control Program Flow Chart

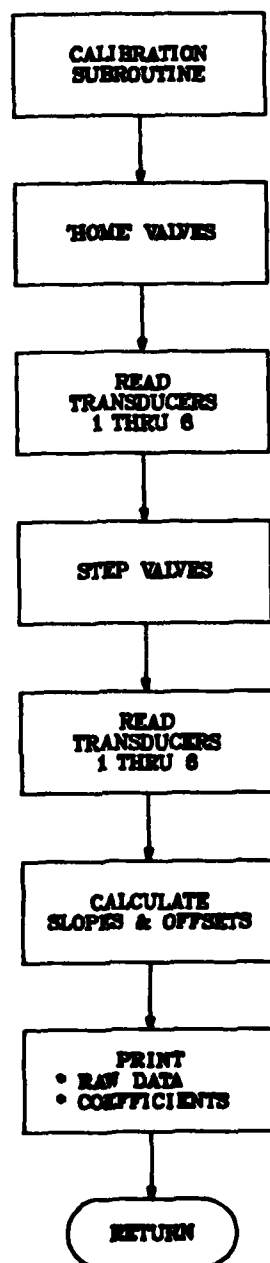


Figure B.3. Pressure Calibration Subroutine Flow Chart

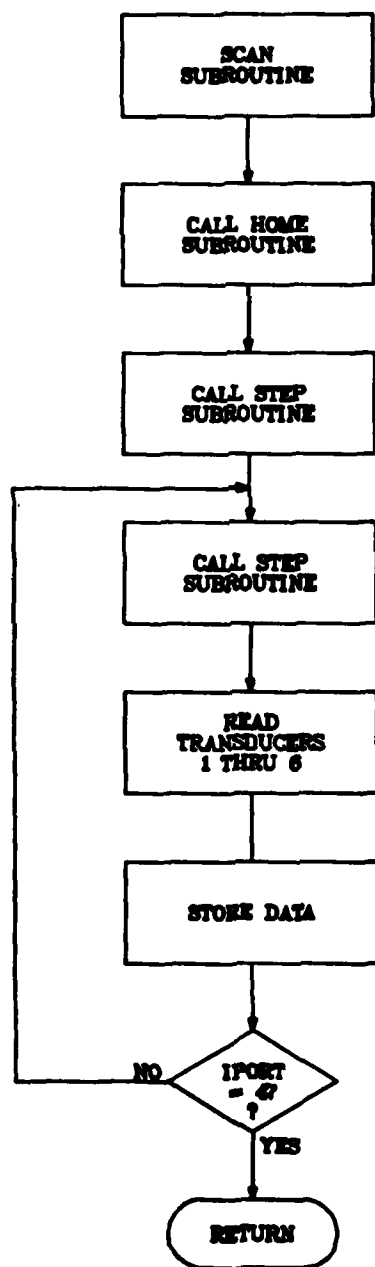


Figure B.4. Valve Port Scanning Subroutine Flow Chart

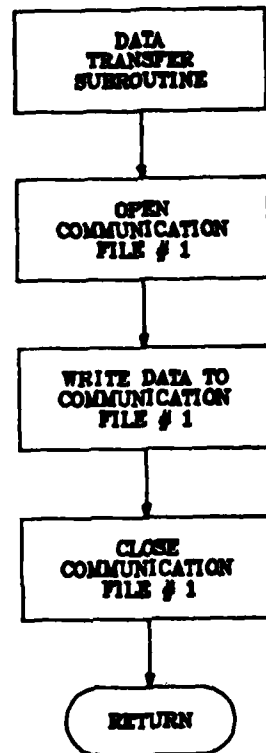


Figure B.5. Data Transfer Subroutine Flow Chart

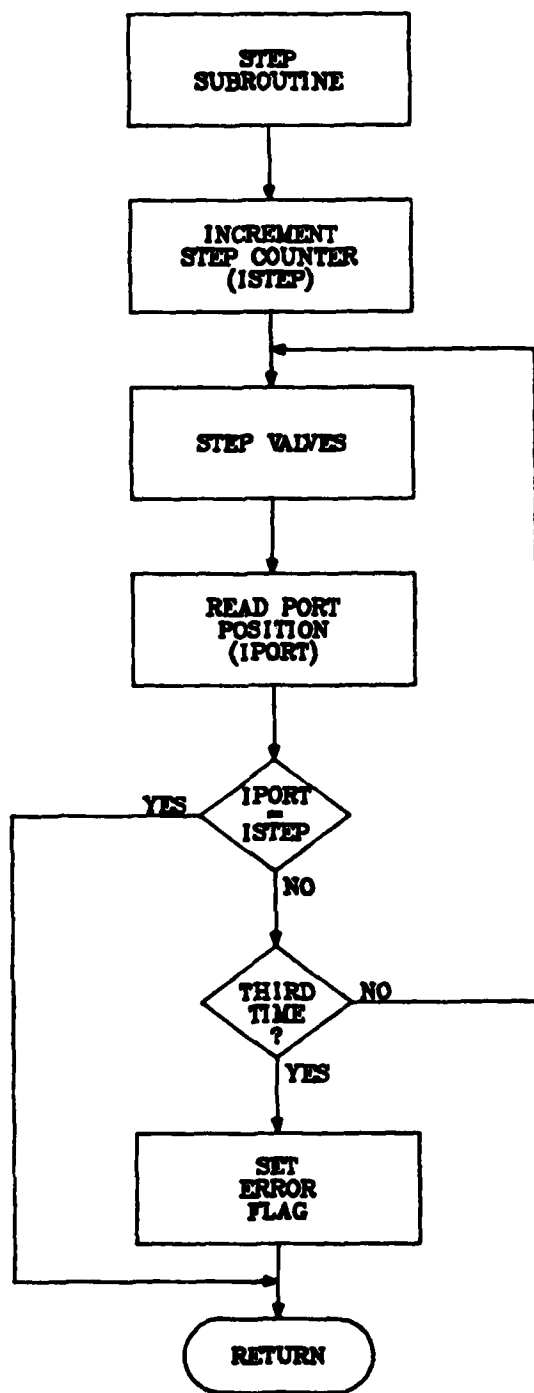


Figure B.6. Scanning Valve Step Subroutine Flow Chart

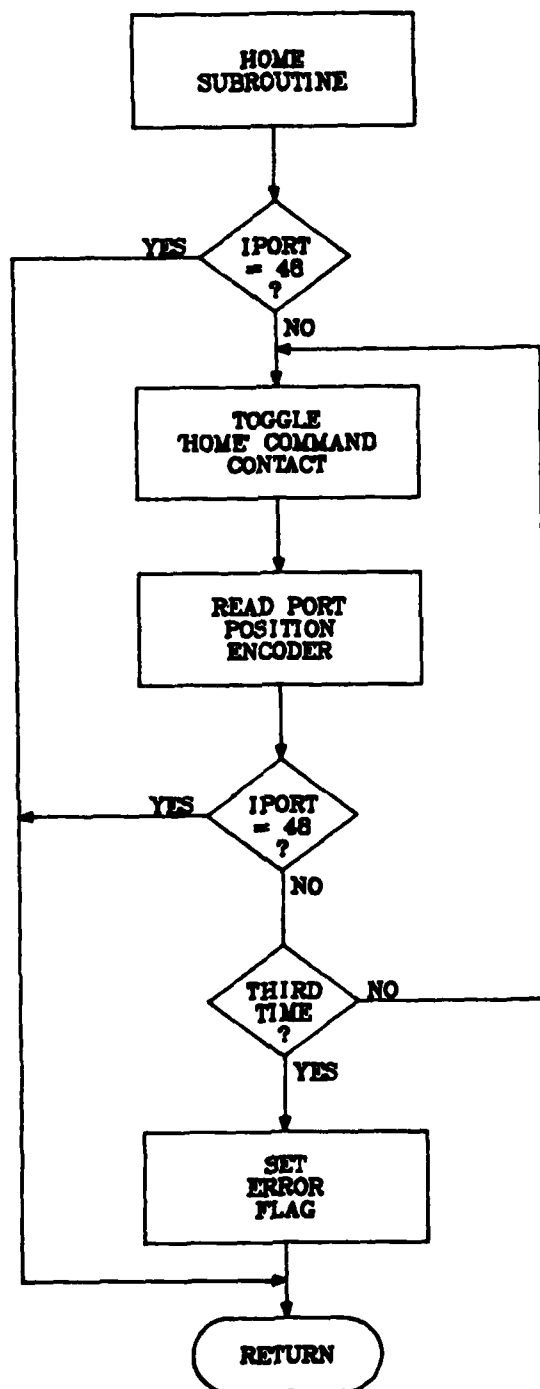


Figure B.7. Scanning Valve Homing Subroutine Flow Chart

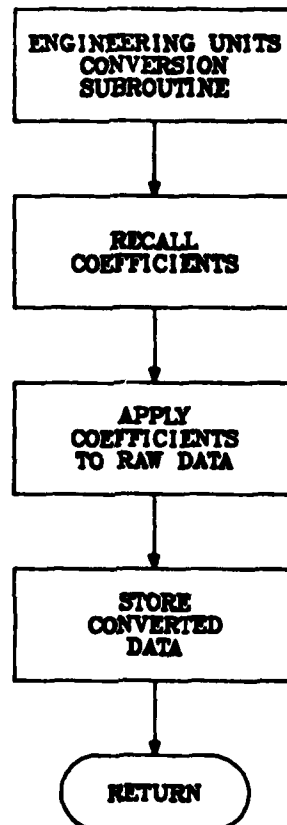


Figure B.8. Data Conversion Subroutine Flow Chart

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END

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